Supplemental Material

Health Impacts of the Built Environment: Within-urban Variability in Physical Inactivity, Air Pollution, and Ischemic Heart Disease Mortality

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This document provides supporting information on the following topics:

I. Walkability scores and land use mix

We used an alternate approach to define neighborhoods (a composite walkability index) to test the robustness of the core findings to our method for defining high- and low-walkability neighborhoods (main text method selects neighborhoods in the highest (or lowest) tertile of all three built environment variables). The composite walkability index (alternate approach) was created by first calculating z-scores for each built environment variable (population density, intersection density, land use mix). At each home location all three z-scores were summed according to equation S1 (adapted from [Marshall et al. 2009]; data on retail floor area ratio was unavailable and therefore was not included here):

$$Walkability = Z_{PD} + Z_{LUM} + 2Z_{ID} \qquad \text{(S1)}$$

Where Z_{PD} is the z-score for population density, Z_{LUM} is the z-score for land use mix, and Z_{ID} is the z-score for intersection density. The coefficient for Z_{ID} reflects the greater walkability importance of intersection density relative to population density and land use mix. For our primary approach, we define high- , low- walkability as locations that fall in the upper tertile of each built environment variable. For the sensitivity analysis (alternate approach) we instead defined high- [low-] walkability neighborhoods as those in the upper [lower] tertile of the composite index (i.e., 33% of the survey population are located in high-walkability neighborhoods and 33% are located in low-walkability neighborhoods), thereby yielding an approximately equal number of people in each neighborhood type. By design, the number of people in high- and low-walkability neighborhoods is larger for the sensitivity analysis (n=9,994 and 10,008, respectively) than for the main approach (n=3,549 and 5,366, respectively). Figure S1 and Table S1 compare findings using the main and alternative approaches for identifying high- and low-walkability neighborhoods.

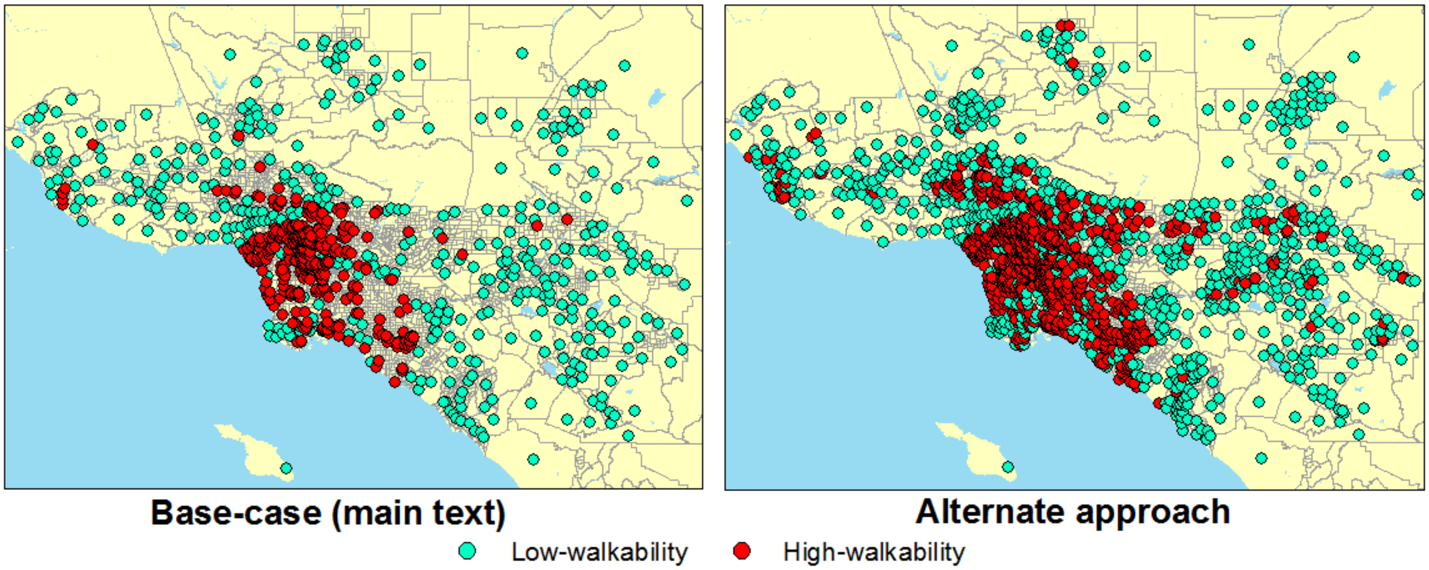


Figure S1. Home locations of survey respondents in high- and low-walkability neighborhoods, by method. By design, the number of individuals included is larger for the alternative approach than for the main approach. Core conclusions are similar between the two methods.

<u>Land use mix</u>: We used the equation in Frank et al. (2004) to calculate land use mix:

$$Land\ use\ mix = -\sum_{i=1}^{n} \frac{p_i \ln p_i}{\ln n} \tag{S2}$$

Here, p_i is the proportion of land use (by area) i and n is the number of land uses. We included four land types: residential, commercial, office, and institutional. All “other” land uses were included for estimating total land area when calculating p_i.

Table S1. Comparison of two methods to calculate walkability

		Mean RR	Proportion above 10th percentile of entire cohort	Population attributable fraction	Total estimated attributable IHD deaths per year (in each subgroup)	Estimated attributable IHD deaths per 100,000 per year[a]
Total sample	**All survey participants (n = 30,007)**					
	Physical inactivity	1.41	0.89	0.27	15.3	51.1 (44.2-58.1)
	NO_x	1.36	0.90	0.25	6.1	20.2 (16.2-25.4)
	$PM_{2.5}$	1.20	0.90	0.16	8.9	29.7 (-1.4-57.7)
	O_3	1.01	0.90	0.01	0.7	2.4 (0.6-4.0)
Main approach	**High-walkability (n = 3,549)**					
	Physical inactivity	1.38	0.84	0.24	1.6	46.1 (39-53)
	NO_x	1.53	0.95	0.34	2.3	27.5 (22-34)
	$PM_{2.5}$	1.22	0.95	0.17	1.2	33.1 (-2-64)
	O_3	1.005	0.80	0.004	0.03	0.7 (0.2-1.2)
	Low-walkability (n = 5,366)					
	Physical inactivity	1.42	0.91	0.28	2.8	53.0 (46-60)
	NO_x	1.22	0.84	0.16	1.6	12.7 (10-16)
	$PM_{2.5}$	1.17	0.83	0.12	1.3	23.7 (-1-47)
	O_3	1.02	0.99	0.02	0.2	4.4 (1-7)
Alternate approach	**High-walkability (n = 9,994)**					
	Physical inactivity	1.39	0.86	0.25	4.8	48.0 (41-55)
	NO_x	1.49	0.95	0.32	6	25.9 (21-32)
	$PM_{2.5}$	1.22	0.94	0.17	3.3	33.2 (-2-63)
	O_3	1.01	0.81	0.005	0.1	0.9 (0.2-1.6)
	Low-walkability (n = 10,008)					
	Physical inactivity	1.42	0.91	0.28	5.3	53.0 (46-60)
	NO_x	1.24	0.84	0.17	3.2	13.7 (11-18)
	$PM_{2.5}$	1.18	0.84	0.13	2.5	24.5 (-1-49)
	O_3	1.02	0.99	0.02	0.4	4.1 (1-7)

[a]Incidence of IHD mortality in CA (age-adjusted): 191.2 deaths/100,000/year (CA men aged 45-54 (used for NO_x: 89.1 deaths/100,000/year). Values in parentheses are 95% confidence intervals based on the 95% CI from the risk estimates in Table 1 (main text).

II. Dose-response: Physical inactivity and air pollution

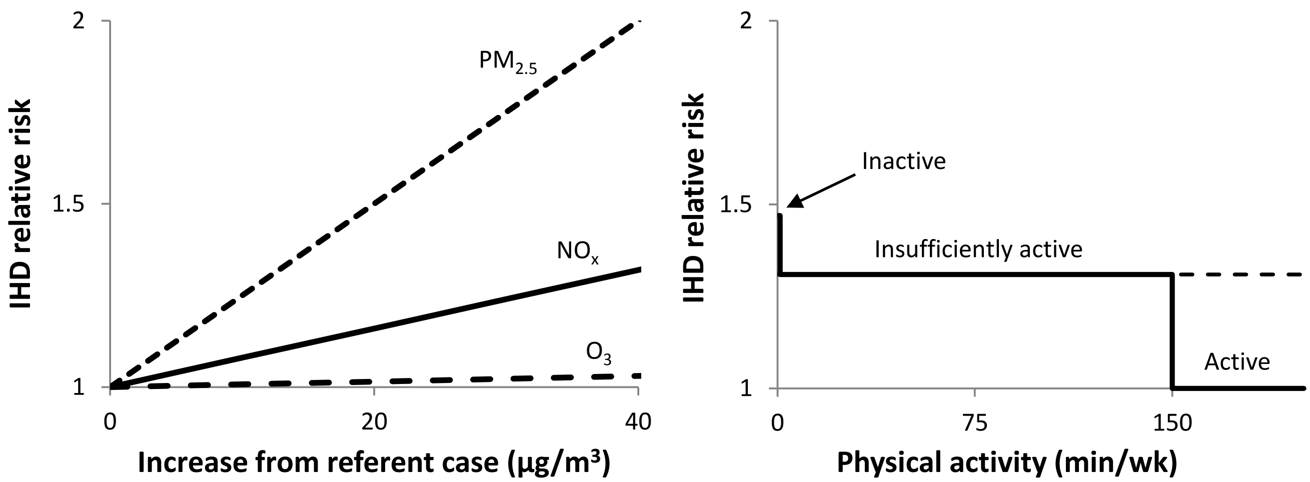


Figure S2. Dose response curves for air pollution (left panel) and physical inactivity (right panel).

III. Population attributable fraction calculations for IHD mortality rates

We also calculated PAF using an alternate disaggregate method using 10 levels of exposure for each air pollutant and 3 levels of exposure for physical inactivity. We followed the methods described in Greenland (2001) to test if our results are sensitive to assumptions associated with the equation used to calculate PAF in the main text as well as a dichotomous definition of exposure. We calculated a mean relative risk and proportion of individuals in each exposure category. We then estimate the population risk and PAF for the total survey population and the subgroup of individuals in high- and low- walkability neighborhoods according to the following equations (Greenland, 2001):

$$RR = \sum_0^k p_k RR_k \tag{S3}$$

$$PAF = \frac{(RR-1)}{RR} \tag{S4}$$

Here, *RR* is the population (or subgroup) relative risk, p_k is the proportion of individuals in each exposure level and RR_k is the relative risk at each exposure level. We used ten, equal interval levels of exposure for $PM_{2.5}$ and O_3. Since the dose-response function for physical inactivity is a three-level stepwise function we used 3 levels of exposure for physical inactivity. Figure S3 shows attributable IHD mortality rates calculated using the method from the main text and the alternate method described above. We found similar trends in risk using both methods.

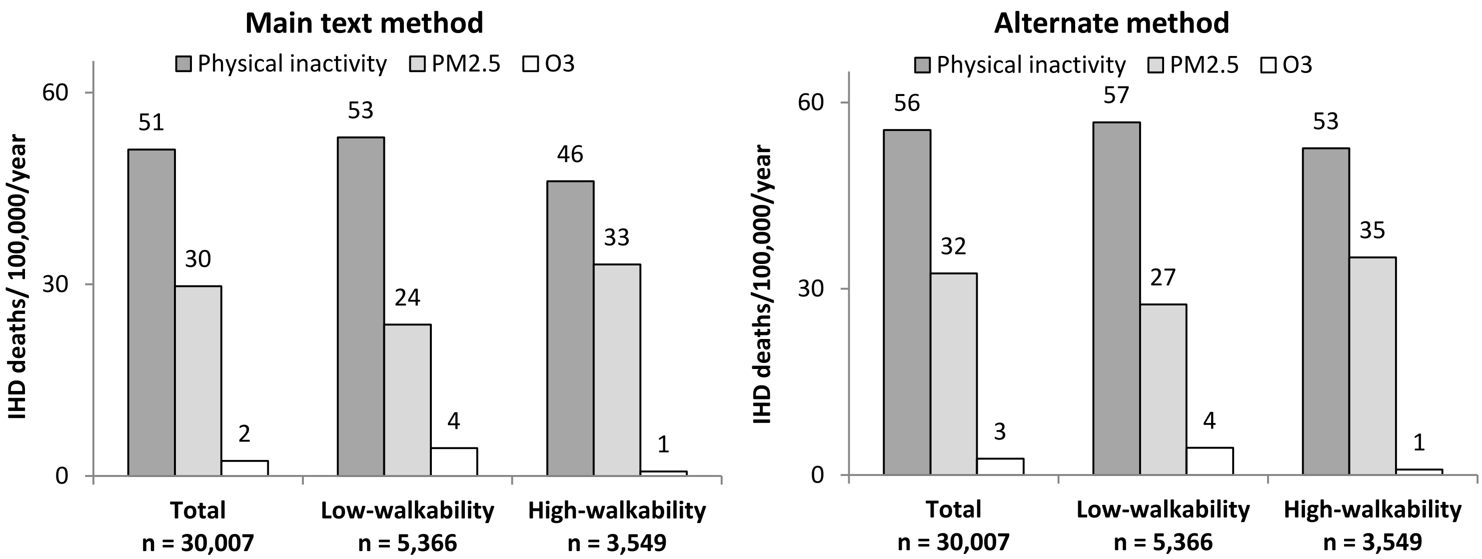


Figure S3. Comparison of the two methods used to calculate population attributable fraction. Left panel: method used in the main text (dichotomous exposure levels); Right panel: an alternate method (multiple exposure levels).

IV. Purpose of physical activities and weekend-weekday activity patterns

Two groups of people are listed in Table S2, Figure S4: (1) “Total sample” (n = 30,007) is the weekday-only sample used throughout the analysis in the main text; (2) “Weekend subsample” and “weekday subsample” refer to the subset of participants who completed a 48-hour survey (n=5,104). For the subsample (n=5,104), total physical activity is similar (<15% difference) between weekend and weekday.

Table S2. Comparison of weekend vs. weekdays and transport vs. leisure physical activity

	N	Average physical activity (min/day)			
		Walking	*Bicycling*	*Fitness*	*Total*
Total Sample					
Total	30,007	3.5	0.4	7.1	11.0
Low-walkability	5,366	1.8	0.3	7.6	9.7
High-walkability	3,549	7.2	0.4	7.0	14.6
Weekend subsample					
Total	5,104	2.4	0.2	9.8	12.4
Low-walkability	916	2.0	0.0	10.6	12.6
High-walkability	661	4.7	0.2	7.4	12.3
Weekday subsample					
Total	5,104	4.4	0.4	6.1	10.9
Low-walkability	916	1.6	0.3	7.9	9.8
High-walkability	661	8.4	0.3	2.8	11.5

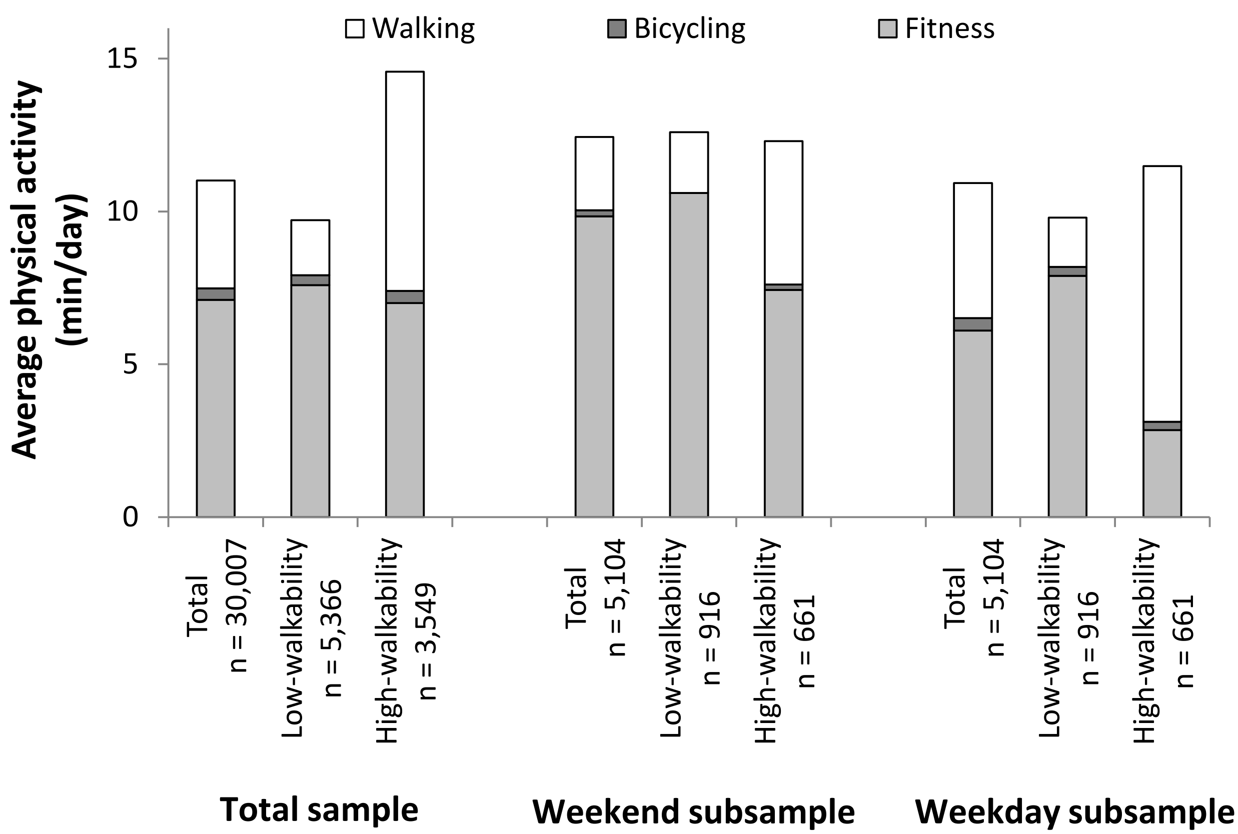


Figure S4. Minutes of physical activity by sample type and purpose.

V. Results stratified by walkability decile

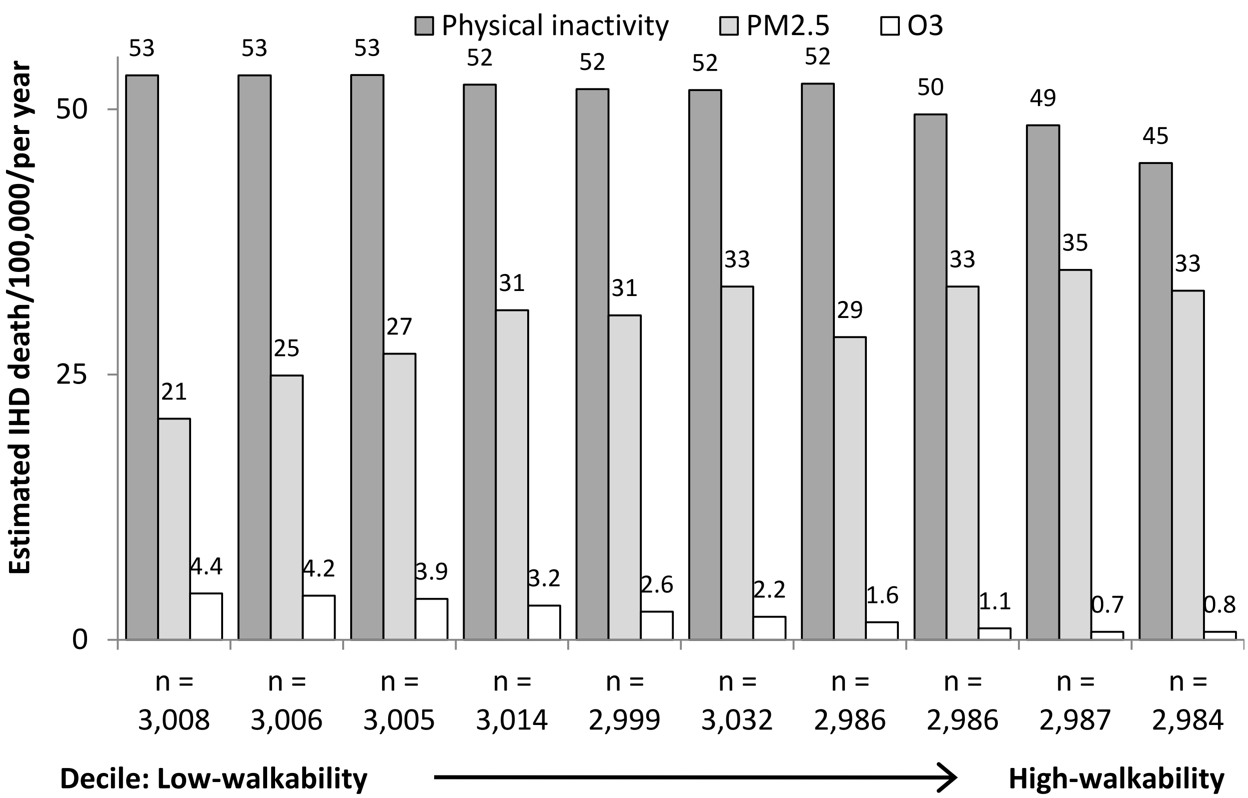


Figure S5. Estimated attributable IHD deaths stratified by walkability decile.

VI. Sensitivity analysis #1: Scaling method for minutes of physical activity

In the main paper, we assumed constant physical activity by day-of-week. To test this assumption we employed a Monte Carlo simulation that redistributed minutes of physical activity for two alternate assumptions: (1) people exercise every two days and (2) people exercise every three days. We held the total minutes of physical activity constant in the population but redistributed minutes to inactive individuals based age, ethnicity, and gender. We found that while the overall proportion of non-sedentary individuals increased, the variability between neighborhoods decreased, suggesting that our core findings are not sensitive to the assumption that daily activity is constant during the week. Table S3 shows the results of our Monte Carlo analysis.

Table S3. Monte Carlo simulation adjusting for assumed frequency of physical activity

	Low-walkability				High-walkability				Estimated IHD mortality difference per 100,000 (low-high walkability)
	Inactive	Insufficiently active	Active	Total	Inactive	Insufficiently active	Active	Total	
***Base case assumption**: non-sedentary exercise every day*	87%	4%	9%	100%	75%	9%	16%	100%	6.9
***Alternative assumption #1**: non-sedentary exercise every 2 days*	71%	14%	15%	100%	59%	23%	18%	100%	4.2
***Alternative assumption #2**: non-sedentary exercise every 3 days*	54%	30%	16%	100%	43%	39%	17%	100%	2.8

VII. Sensitivity analysis #2: Air pollution model

We compared our air pollution exposure estimates to alternate modeling methods in the South Coast Air Basin. Table S4 shows mean air pollution exposures for the survey population using data available for alternate air pollution models in southern California. We were only able to compare certain pollutants between models. Our estimates show that while central tendencies vary by model, differences in exposure (and subsequently risks) between neighborhoods are consistent in most cases. For example, average individual relative risks for O_3 using IDW [CAMx] were 1.02 [1.02] for high-walkability neighborhoods and 1.09 [1.12] for low-walkability neighborhoods. Similarly, for NO_x using IDW [CAMx] risks were 1.53 [1.55] in high-walkability neighborhoods and 1.22 [1.08] in low-walkability neighborhoods. IDW typically resulted in the smallest urban-variability among the models evaluated here, indicating that our estimates may be conservative for differences in air pollution exposure between neighborhoods.

Table S4. Mean air pollution exposures by model type

	NO (µg/m^3)			NO_2 (µg/m^3)			O_3 (µg/m^3)			$PM_{2.5}$ (µg/m^3)		
	IDW	**CAMx**	**LUR**	**IDW**	**CAMx**	**LUR**	**IDW**	**CAMx**	**LUR**	**IDW**	**CAMx**	**LUR**
All	36	11	-	49	44	38	99	60	-	22	-	-
Low-walkability	25	3	-	42	22	25	111	78	-	20	-	-
High-walkability	48	21	-	58	63	48	86	45	-	23	-	-
Difference (high-low walkability)	23	18	-	16	41	23	-25	-33	-	3	-	-

IDW = inverse distance weighted; CAMx = comprehensive air quality model with extensions (dispersion model); LUR = land use regression. Note: For O_3 CAMx modeled annual average concentrations, IDW modeled the annual average of daily 1-hour maximum concentrations.

VIII. Sensitivity analysis #3: Physical activity dose-response

Here, we employ a linear dose-response for physical activity. See Figure S6; each curve was derived from values given by the WHO (2004) (Table 1 in the main text). The stepwise curve represents values given directly in WHO (2004). The remaining lines reflect linear dose-response relationships employed as sensitivity analyses: a lower bound, upper bound, and midpoint estimate. Table S5 is a comparison of mean relative risks and IHD mortality rates for the survey population (n = 30,007) using each dose-response curve. We found only minor differences between linear and stepwise dose-responses. We also observe only small differences between the upper and lower bound curves. Note that when comparing between dose-response curves not only the slope changes, but so does the population that is exposed. For example, the lower bound curve reaches a RR = 1 at 150 minutes while the upper bound reaches a RR = 1 at 440 minutes. We chose to employ the step-wise dose response for our main analysis as it most directly reflects current physical activity guidelines as described in WHO (2004).

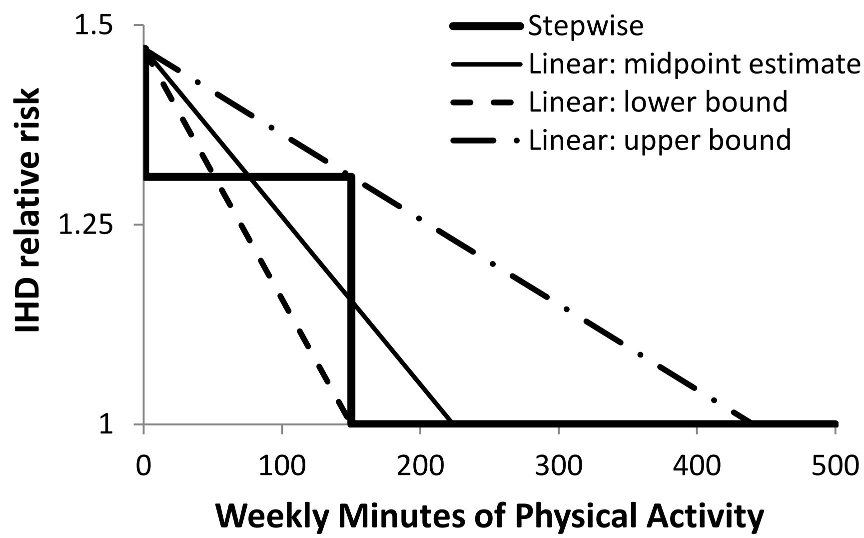


Figure S6. Dose-response curves for physical activity.

Table S5. Comparison of core results for the survey population using various dose-response curves for physical activity

Dose-response	RR physical inactivity	Proportion exposed	Population attributable fraction	IHD mortality per 100,000 per year
Stepwise (WHO 2004)	1.41	0.89	0.27	51.1
Linear: midpoint estimate	1.41	0.91	0.27	52.0
Linear: lower bound	1.40	0.89	0.26	50.6
Linear: upper bound	1.42	0.95	0.29	54.7

IX. Results stratified by age, SES, and built environment variables

Table S6 shows average survey participant relative risks (air pollution and physical inactivity) as well as descriptive statistics for weekly minutes of physical activity stratified by built environment and SES variables (i.e., we calculate a relative risk for each individual [for each risk factor] and then average those relative risks within each strata). We use the same reference case for all relative risk calculations (>150 minutes of physical activity; 10th percentile of air pollution exposure).

Table S6. Summary statistics of travel survey data by SES and built environment strata

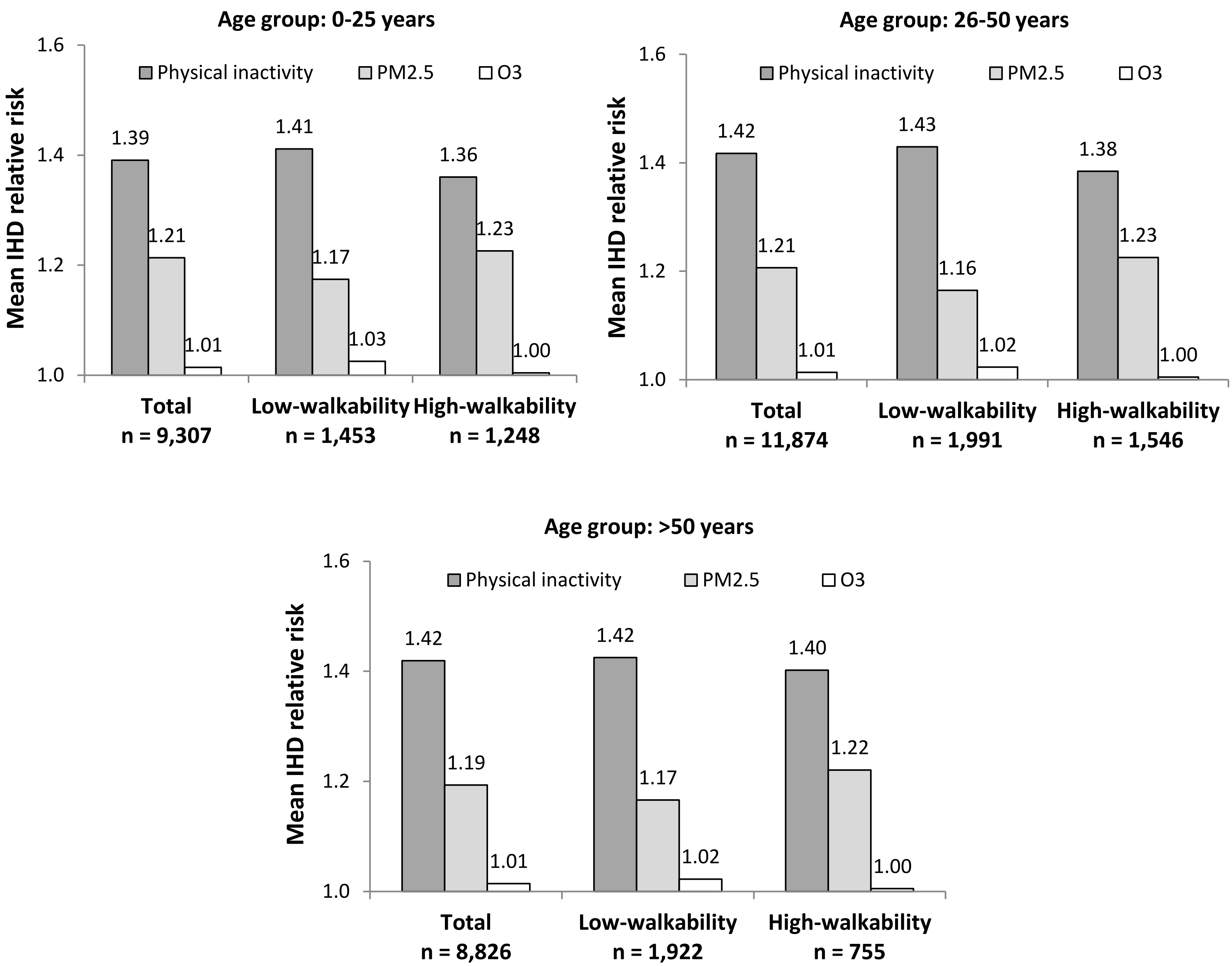
		n	Total physical activities (min/wk)	Average per capita minutes of physical activity	Number of people with >0 minutes of activity	Average physical activity: non-sedentary individuals (min/wk)	% of people > 0 minutes of activity	RR physical inactivity	Mean RR $PM_{2.5}$	Mean RR NO_x	Mean RR O_3
	All	30,007	2,312,016	77.0	4,957	466	16.5%	1.41	1.20	1.36	1.014
Population Density	*Low density*	10,001	690,291	69.0	1,319	523	13.2%	1.42	1.18	1.24	1.023
	Medium density	9,999	737,989	73.8	1,525	484	15.3%	1.41	1.21	1.34	1.014
	High density	10,007	883,736	88.3	2,113	418	21.1%	1.39	1.23	1.51	1.005
Intersection Density	*Low density*	10,072	703,689	69.9	1,354	520	13.4%	1.42	1.19	1.26	1.021
	Medium density	10,087	733,684	72.7	1,586	463	15.7%	1.41	1.21	1.36	1.014
	High density	9,848	874,643	88.8	2,017	434	20.5%	1.40	1.22	1.47	1.007
Land Use Mix	*Low LUM*	10,004	686,623	68.6	1,338	513	13.4%	1.42	1.18	1.28	1.020
	Medium LUM	10,004	732,718	73.2	1,608	456	16.1%	1.41	1.22	1.39	1.013
	High LUM	9,999	892,675	89.3	2,011	444	20.1%	1.40	1.22	1.43	1.010
Walkability (tertiles)	*Low*	5,366	364,770	68.0	672	543	12.5%	1.42	1.17	1.22	1.023
	Medium	21,092	1,585,143	75.2	3,401	466	16.1%	1.41	1.21	1.37	1.013
	High	3,549	362,103	102.0	884	410	24.9%	1.38	1.22	1.53	1.005
Walkability (z-scores)	*Low*	10,008	687,316	68.7	1,326	518	13.2%	1.42	1.18	1.24	1.022
	Medium	10,005	720,419	72.0	1,450	497	14.5%	1.42	1.22	1.36	1.014
	High	9,994	904,281	90.5	2,181	415	21.8%	1.39	1.22	1.49	1.006
Gender	*Male*	14,875	1,262,681	84.9	2,502	505	16.8%	1.41	1.20	1.36	1.014
	Female	15,132	1,049,335	69.3	2,455	427	16.2%	1.41	1.20	1.36	1.014
Ethnicity	*White*	18,094	1,448,321	80.0	2,677	541	14.8%	1.41	1.19	1.30	1.016
	Non-white	11,913	863,695	72.5	2,280	379	19.1%	1.40	1.23	1.45	1.011
Residence Type	*Detached*	20,336	1,497,265	73.6	2,983	502	14.7%	1.42	1.20	1.34	1.016
	Duplex	1,023	78,694	76.9	190	414	18.6%	1.40	1.20	1.43	1.010
	Condo/townhome	2,793	243,474	87.2	583	418	20.9%	1.39	1.20	1.38	1.010
	Apartment	4,797	435,015	90.7	1,059	411	22.1%	1.39	1.22	1.43	1.010
Age	*0-17*	6,431	550,165	85.5	1,692	325	26.3%	1.38	1.21	1.37	1.015
	18-65	19,538	1,372,350	70.2	2,713	506	13.9%	1.42	1.20	1.37	1.014
	65+	4,038	389,501	96.5	552	706	13.7%	1.42	1.19	1.33	1.014
Education	*High school or less*	15,493	1,132,397	73.1	2,841	399	18.3%	1.41	1.21	1.38	1.015
	College or more	13,861	1,153,047	83.2	2,048	563	14.8%	1.41	1.19	1.34	1.013
Income	*0-35K*	8,593	695,891	81.0	1,785	390	20.8%	1.40	1.22	1.42	1.013
	35-75K	9,819	709,737	72.3	1,431	496	14.6%	1.42	1.20	1.35	1.015
	75K+	8,221	644,805	78.4	1,212	532	14.7%	1.41	1.19	1.32	1.014
Income/ Ethnicity	*High income/white*	6,400	538,594	84.2	978	551	15.3%	1.41	1.18	1.30	1.015
	Low income/non-white	5,352	459,550	85.9	1,303	353	24.3%	1.38	1.23	1.47	1.010

Table S7. Core results stratified by income, ethnicity, and walkability

		Mean RR	Proportion above 10^{th} percentile of entire cohort	Population attributable fraction	Total estimated attributable IHD deaths per year (in each subgroup)	Estimated attributable IHD deaths per 100,000 per year[a]
Low income non-white	**High-walkability (n = 1,327)**					
	Physical inactivity	1.37	0.82	0.23	0.59	44.4
	NO_x	1.58	0.95	0.35	0.90	29.0
	$PM_{2.5}$	1.23	0.95	0.18	0.45	34.2
	O_3	1.004	0.74	0.00	0.01	0.6
	Low-walkability (n = 440)					
	Physical inactivity	1.41	0.90	0.27	0.23	51.6
	NO_x	1.2	0.78	0.14	0.11	11.1
	$PM_{2.5}$	1.19	0.78	0.13	0.11	24.7
	O_3	1.03	0.99	0.02	0.02	4.8
High income, white	**High-walkability (n = 392)**					
	Physical inactivity	1.38	0.83	0.24	0.18	45.7
	NO_x	1.43	0.97	0.29	0.22	24.1
	$PM_{2.5}$	1.22	0.97	0.18	0.13	33.7
	O_3	1.006	0.95	0.01	0.00	1.0
	Low-walkability (n = 1,684)					
	Physical inactivity	1.42	0.90	0.27	0.88	52.4
	NO_x	1.21	0.81	0.15	0.47	12.0
	$PM_{2.5}$	1.15	0.82	0.11	0.35	21.0
	O_3	1.02	1.00	0.02	0.07	3.9

[a]Incidence of IHD mortality in CA (age-adjusted): 191.2 deaths/100,000/year (CA men aged 45-54 (used for NO_x: 89.1 deaths/100,000/year).

We also investigated differences in relative risk by age. Figures S6-S8 show mean IHD relative risks in 3 age groups: 0-25 years, 26-50 years, and >50 years. We found similar trends in risk between neighborhoods for each age group. Between-neighborhood risk differences for physical activity were largest for the youngest age group and smallest for the oldest age group. This suggests that, for physical activity, the built environment may influence younger age groups more than older age groups. We also give descriptive statistics for age stratified by level of air pollution exposure and neighborhood type in Table S8.



Figures S6-S8. Mean IHD relative risks for 3 age groups (0-25 years, 26-50 years, >50 years) for each neighborhood type (high- and low-walkability neighborhood).

Table S8. Age distribution by level of air pollution exposure and neighborhood walkability

	$PM_{2.5}$ exposure			**O_3 exposure**			**Walkability**		
	low	*medium*	*high*	*low*	*medium*	*high*	*low*	*medium*	*high*
n	10,067	9,719	10,221	10,062	10,108	9,837	5,366	21,092	3,549
Range (μg/m^3)	0-21.5	21.6-23.5	>23.5	0-88	89-105	>105	-	-	-
Mean age	39.6	38.6	35.5	37.2	39.2	37.1	40.9	37.8	34.0
Standard deviation age	22.3	21.5	21.6	21.6	21.9	22.1	22.2	22.0	20.3

References

Greenland S. 2001. Attributable fractions: Bias from broad definition of exposure. Epidemiology 12(5):518-520.